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Does self-monitoring diet and physical activity behaviors using digital technology support adults with obesity or overweight to lose weight? A systematic literature review with meta-analysis

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Summary

Establish whether digital self-monitoring of diet and physical activity is effective at supporting weight loss, increasing physical activity and improving eating behavior in adults with obesity or overweight, and determine the intervention components that might explain variations in its effectiveness. A systematic search of MEDLINE, Embase, PsycINFO, Web of Science, Scopus, Cinahl, and CENTRAL identified 4068 studies, of which 12 randomized controlled trials were eligible and included in the review. A random-effect meta-analysis evaluated intervention effectiveness and subgroup analyses tested for effective intervention content. Twelve studies were included in the review and meta-analysis. Digital self-monitoring of both diet and physical activity had a statistically significant effect at supporting weight loss (mean difference [MD] = -2.87 [95% CI −3.78, −1.96], $P < 0.001$, $I^2 = 69\%$), improving moderate physical activity (standardized mean difference [SMD] = 0.44 [95% CI 0.26, 0.62], $P < 0.001$, $I^2 = 0\%$), and reducing calorie intake (MD = −181.71 [95% CI −304.72, −58.70], $P < 0.01$, $I^2 = 0\%$). Tailored interventions were significantly more effective than nontailored interventions ($x^2 = 12.92$, $P < 0.001$). Digital self-monitoring of physical activity and diet is an effective intervention to support weight loss in adults with obesity or overweight. This effect is significantly associated with tailored advice. Future studies should use rigorous designs to explore intervention effectiveness to support weight loss as an adjunct to weight management services.

KEYWORDS
digital technology, obesity, overweight, weight loss

Abbreviations: ACC, American College of Cardiology; AHA, American Heart Association; BCT, behavior change technique; BMI, body mass index; LMVPA, light, moderate, and vigorous physical activity; MD, mean difference; MeSH, Medical Subject Headings; MVPA, moderate to vigorous physical activity; NCD, noncommunicable disease; RCT, randomized controlled trial; RoB, risk of bias; SMD, standardized mean difference; TOS, The Obesity Society; WHO, World Health Organization.

1 | INTRODUCTION

1.1 | Obesity, overweight, and health behavior change

The prevalence of obesity has been increasing worldwide over the past 50 years and obesity is now a significant public health challenge.[1] In 2016, around 13% of the world's adult population was classified as obese and 39% as overweight.[2] By 2030, it is projected that excess bodyweight will present a loss of 26–55 million quality-adjusted life years for USA and UK combined.[3,4] Obesity is a major risk factor for a range of long-term health conditions, such as cardiovascular disease, cancer, and diabetes mellitus, that account for significant morbidity and mortality worldwide.[1] The COVID-19 pandemic has revealed further alarming associations between the prevalence of obesity and increased susceptibility to health risks, highlighting yet again the severity of the obesity crisis.[5] If rising obesity rates are not dealt with, obesity-related health conditions will continue to place an enormous burden on health care systems and their resources.

A lack of physical activity and increased intake of energy-dense and high-fat foods are both considerable factors that have contributed to the obesity crisis.[6] The best way to support people with obesity or overweight lose weight is to encourage physical activity and healthy diet, as part of usual care advice by their health care providers.[7] Evidence suggests that behavioral interventions aiming to improve physical activity and/or eating behavior have modest effects at supporting adults with obesity lose weight.[8] Although promising, these behavioral interventions require many resources, are time-consuming, and are not easy to disseminate and implement, often requiring frequent and repeated face-to-face contacts with health care professionals whose time is limited and generally expensive.

1.2 | Digital health interventions and self-monitoring

Digital interventions have the potential to reach large numbers of people[9] and at a low cost, while also engaging users in an interactive format and in real-time, often with the potential to apply theory and techniques to support behavior change to the individual.[10] Behavioral interventions that enable individuals to self-regulate their behaviors and exercise control over the process of health behavior change might be more effective at promoting behavior change and associated health outcomes than those outside of an individual's perceived control.

One important element of self-regulation is to monitor health-related behaviors. Self-monitoring of behavior is a behavior change technique (BCT) whereby an individual monitors and records their behavior(s) as part of a behavior change intervention.[11] Research suggests that self-monitoring both physical activity and eating behavior could facilitate weight loss.[12] Digital self-monitoring interventions enable participants to monitor their health behaviors, either by logging behavioral performance themselves or utilizing data from automatically recorded behaviors using sensors or wearable technology. Such interventions enable individuals to access tailored, automated, and real-time support. If integrated into usual weight management services, they could also provide ongoing support for improving physical activity and eating behaviors and inform obesity treatment and service provision. However, the effect of digital self-monitoring of both eating behavior and physical activity on weight loss and on changing these behaviors in adults with obesity or overweight has not been evaluated yet.

Previous reviews and meta-analyses on the effectiveness of digital interventions at promoting weight loss have not focused specifically on self-monitoring behavioral interventions.[13–15] For example, a systematic review on app-based lifestyle interventions targeting physical activity, diet and sedentary behavior in adults and children provided modest evidence for the efficacy of apps at improving each of these behaviors, but with no evidence on how improvements in these behaviors might have been achieved to impact on weight loss.[16]

This review aims to inform knowledge about the effectiveness of digital interventions that enable self-monitoring of both eating behavior and physical activity at improving weight loss in adults with obesity or overweight. A recent review has evaluated the association between self-monitoring of weight loss and adherence to digital self-monitoring.[17] However, the present review evaluates the effects of behavioral self-monitoring on improving weight loss using quantitative meta-analysis.

This systematic literature review has the following objectives:

1. To evaluate the effectiveness of digital self-monitoring of eating behavior and physical activity at promoting weight loss, increasing physical activity and reducing energy intake in adults with obesity or overweight.
2. To explore which behavior change techniques and strategies might explain variations in intervention effectiveness.

2 | METHODS

2.1 | Protocol and registration

This review is registered with PROSPERO (ID: CRD42020202010).

2.2 | Study eligibility

In order to identify the studies eligible for inclusion in this review, the PICOS framework was used as outlined in Table S1.

2.2.1 | Participants

Study participants eligible for inclusion in the review were adults, aged 18 or over, with obesity or overweight. This review adopted the

definition of the World Health Organization: overweight as those having a body mass index (BMI) more than or equal to 25 and obesity as those having a BMI more than or equal to 30.[18] Studies were excluded if they included any of the following: nonoverweight participants, children, or parent–children dyads.

2.2.2 | Interventions

Interventions eligible for inclusion were those that enabled participants to self-monitor both their eating behavior (i.e., related to energy intake) and physical activity using digital technology. Digital technologies considered eligible for this review included text messages, web-based applications, mobile phone applications (apps), or a combination of these. Wearable or sensing technologies, such as pedometers for physical activity, could be used to facilitate digital self-monitoring of the health behaviors.

Digital interventions that utilised additional nondigital elements, such as face-to-face coaching or telephone calls were eligible for inclusion if these additional components were supplementary to the digital self-monitoring behavioral intervention. Digital interventions that included very minimal nondigital advice (e.g., educational information about eating behavior and physical activity) were eligible for inclusion primarily due to the population of interest being people that need advice to lose weight, which in most cases includes advice for or signposting to lifestyle management programs.[7]

2.2.3 | Comparators

Eligible comparators were those that did not enable participants to self-monitor diet and physical activity digitally. This included face-to-face communication methods, usual care, paper-based communications, paper self-monitoring of diet and/or physical activity, and digitally available communications not enabling self-monitoring of both diet and physical activity behaviors, or no specified intervention.

2.2.4 | Outcomes

Studies had to report an outcome measurement of weight loss (primary outcome) and an outcome of either physical activity or eating behavior (secondary outcomes). Objectively measured weight (e.g., using a digital electronic scale) in kg or BMI were acceptable outcome measurements for the primary outcome. For physical activity, objective measurements only (e.g., using a pedometer or accelerometer) were acceptable measurements for the physical activity outcome, and for diet any self-reported measurement (e.g., energy intake in kcal or in kJ per day) was considered eligible for inclusion.

2.2.5 | Study design

Only randomized controlled trials (RCTs) were eligible for inclusion in this review. Quasi-RCTs were not eligible for inclusion.

2.3 | Literature search

A search of the electronic databases MEDLINE via Ovid, Embase via Ovid, Web of Science, PsycINFO, Scopus, Cinahl, and Cochrane Central Register of Controlled Trials (CENTRAL) was conducted during August 2020 to identify studies eligible for this review. The search strategy was developed using key words to map the criteria onto the PICOS framework and by reviewing the key words used by other relevant reviews. A combination of free text search terms and Medical Subject Headings (MeSH terms) was used. The search strategy was first developed in MEDLINE via Ovid (Figure 1) to identify studies that contained at least one of the key search terms in the digital category (#1), study design (#2), secondary outcome of diet or physical activity (#3), and population and primary outcome (#4) in the study title or abstract. Self-monitoring was not included as a term in the search strategy to avoid missing potential studies that had not defined interventions as such in their study title or abstract.

Search filters for RCTs, humans, English language, publication date after 2000, and adults were also applied. Grey literature was not searched. The references of all included studies were screened to identify any additional studies eligible for inclusion.

2.4 | Study selection

Records returned from the seven databases were imported into EndNote and duplicates removed by title and author. The remaining

#1 (text messaging OR SMS OR short messaging service OR web OR internet OR wristband or wearable technolog* OR fitbit or activity tracker* OR wearable device* OR wearable sensor* OR sens* technolog* OR digital or computer OR app* OR mobile health or mhealth OR smartphone or technolog* OR cell phone OR cellphone OR mobile phone).ab.

AND

#2 RCT OR trial* OR random*

AND

#3 diet* OR nutrition* OR "physical activit*" OR exercise* [MeSH] Terms

AND

#4 (Obesity or Body Mass Index or body mass index or bmi or BMI or (body adj (weight or mass)) or Body Weight or overweight).ab.

FIGURE 1 MEDLINE via Ovid search terms

studies were then imported into the systematic review web application, *Rayyan*, that enables easy and independent screening of studies and collaboration between reviewers.[19]

The first stage after importing into *Rayyan* was to screen all studies by abstract and title. Studies had to meet all three criteria when abstract screening: (a) the study had an RCT design, (b) participants were adults with obesity or overweight, and (c) the intervention was facilitated digitally. If these criteria were all met, then the study was considered for full-text screening. Studies eligible for full-text screening were then screened in detail against the inclusion and exclusion criteria. This included ensuring that the behavioral intervention was conveyed digitally and that the trial reported an outcome for weight loss and an outcome for either physical activity or eating behavior. Two reviewers (RB and AK) independently completed full-text screening and met to discuss agreement for final inclusion and exclusion. Studies that met all the inclusion criteria at full-text screening were included in the review. Disagreements was resolved by involving a third reviewer (SS). Reasons for exclusion were noted in the Rayyan online application. Eligible studies were then taken forward for data extraction.

2.5 | Data extraction

An excel data extraction form was used to extract data from included studies. This consisted of the following three sections: study characteristics, description of the intervention-comparator groups, and outcomes. When more than one intervention group was reported in the trial, the group that received the most enhanced and purely digital version of the behavioral intervention was selected and coded as the intervention group, and the less enhanced/nondigital intervention as the comparator.

Data reporting weight in kg or BMI, objectively measured physical activity and self-reported eating behavior, was extracted. All outcomes were continuous; thus, we extracted the values for the mean, standard deviations (SD) or confidence intervals (95% CI), and the number of participants in each arm. For the primary outcome of weight loss, we extracted the mean change at the end of the intervention, adjusted for baseline values. For the secondary outcome of behavior change, we extracted the unadjusted data at follow-up (at the end of intervention when multiple follow-up points were recorded).

If studies did not report final values for the secondary outcome, but reported the change from baseline to follow-up, then the final value was calculated from these by extracting (or adding) the change from (to) the baseline. When follow up SD was not reported, the baseline SD was entered in the analysis. Results from an intention-to-treat analysis were extracted, unless there was no intention-to-treat analysis in which case results based on available cases were extracted.

2.6 | Risk of bias in individual studies

To assess the risk of bias within individual studies, the *Cochrane Risk of Bias tool Version 2* was used (RoB 2).[20] The primary review outcome, that is, weight loss, at the end of the intervention was selected to be assessed.

2.7 | Coding intervention content

To explore the active intervention strategies combined with the self-monitoring of physical activity and diet that might explain intervention effectiveness, we used the BCT Taxonomy v1[11] and coded the content that was unique for each of the intervention and comparator groups. We also coded whether or not the interventions provided tailored advice to the individual. We coded interventions as "tailored" when they provided different messages based on participants' individual characteristics. Two reviewers (RB and AK) independently coded studies and discussed coding; if disagreement remained, a third reviewer (SS) provided advice until consensus was achieved. BCTs were marked with a cross to signify higher or lower confidence in coding. One reviewer (RB) summarized coding for further analysis.

2.8 | Meta-analysis

A meta-analysis was conducted to quantitatively summarize the results, in the form of an overall weighted effect estimate. A conclusion about the statistical significance of the pooled effect size was obtained through the meta-analysis, conducted using Review Manager (RevMan) version 5.4[21] software.

2.8.1 | Selection of outcomes

The selection of the outcomes included in the meta-analyses was based on the following criteria: for the primary outcome of weight loss, weight in kg was included in the analysis, and if not reported, weight in BMI was selected. For the physical activity outcome, if more than one units of outcome (e.g., steps and hours of physical activity) was reported per objective outcome measurement, then the unit of outcome most comparable across studies was included in the meta-analysis. For the eating behavior, energy intake in kcal per day or kJ per day was selected.

2.8.2 | Summary statistic

Both the primary and secondary outcomes were continuous; therefore, either the mean difference (MD) or the standardized mean difference (SMD) was appropriate effect estimate.[22] Because the primary outcome of weight and the secondary outcome of diet (energy intake) were measured with the same or similar methods across all studies, the MD was selected as the summary statistic. However, physical activity was measured using varied units of outcome, and therefore, the SMD was selected as the summary statistic to standardize the results.

2.8.3 | Synthesis of results

The random-effects model was used to estimate the weighted pooled effect for each outcome to account for the distribution of the true effect across the individual studies.[23] The I^2 statistic was used as a measure of heterogeneity that describes the percentage of variation across studies that is due to heterogeneity rather than chance.[24] Heterogeneity above 60% was considered substantial and thus it was explored further with subgroup tests. Descriptive statistics were used to summarize the intervention content coded for each of the intervention and comparator groups. Subgroup analysis explored the intervention content that explained statistically significant variance in the intervention effect on the primary outcome. Publication bias was examined by producing funnel plots for each of the three outcomes assessed in the meta-analysis.

3 | RESULTS

3.1 | Included studies

Overall, 5008 studies were identified from the searches. After studies were imported and duplicates removed in Endnote, 4068 studies were retained for abstract and title screening. After abstract and title screening, 4025 studies were excluded, with reasons for exclusion recorded. The remaining 43 studies were taken forward for full-text screening of which 11 studies met all the inclusion criteria. The remaining 32 studies were excluded with the reason for exclusion noted. An additional study was identified through checking the reference lists of the 11 eligible studies. Thus, data were extracted from the total of 12 studies, which were included in the analysis. The PRISMA diagram[25] (Figure 2) describes the study selection process.

3.2 | Study characteristics

Of the 12 studies identified through the systematic search, 11 studies were individual randomized controlled trials, and one study (i.e., Mehring et al[26]) was a cluster randomized controlled trial. The characteristics of the included studies are presented in the Table S2. Seven studies were conducted in the United States, three were conducted in Australia, one in Germany, and one in the United Kingdom. The total number of participants included in the analysis was 1190. Study duration ranged from three to 12 months.

Overall, all interventions were in majority delivered by a digital medium that included mobile phone applications, websites, text messages, and some combinations of these. A description of the content for each of the intervention and the comparator groups per study is provided in Table S3. A description of the outcomes is illustrated in Table 1. Four trials had multiple intervention arms; thus, the purely digital intervention arm was selected as the intervention in Allen et al,[27] Glasgow et al[31] and Pellegrini et al,[34] and the enhanced digital intervention in Collins et al.[29]

3.3 | Risk of bias

Figure 3 provides a breakdown of the risk of bias assessment. Four trials were assessed as having a high risk of bias, three trials presented some concerns of bias and four trials were concluded as having a low risk of bias. An additional risk of bias assessment was conducted for the cluster randomized controlled trial Mehring et al[26] with an overall assessment of high risk of bias concluded.

3.4 | Meta-analyses

Eleven out of the 12 included studies provided results for the primary outcome weight in kg. Glasgow et al[31] reported results for weight loss in BMI; thus, all studies reporting weight in Kg and one study reporting weight in BMI were included in the meta-analysis for the weight loss outcome. For the eating behavior outcome, the most comparable measure across the studies was energy intake in kcal or kJ per day, reported by six studies. Studies reporting kJ units were converted to kcal; thus, the MD was used as the summary statistic. Five studies provided results for the objectively measured physical activity outcome using a variety of units of measure; thus, the SMD was used as the summary statistic. The results were synthesized in three meta-analyses: weight, energy intake, and moderate physical activity. A summary of included data in the meta-analyses is presented in Table 1.

3.4.1 | Weight loss

The overall pooled effect estimate of the mean reduction in weight was −2.87 (95% CI −3.78, −1.96), suggesting significant weight loss in the intervention group compared with control (Figure 4). The I^2 value of heterogeneity was 69%, indicating that there is substantial heterogeneity between studies in the meta-analysis.

3.4.2 | Physical activity

The overall pooled effect estimate of the standardized mean difference in physical activity was 0.44 (95% CI 0.26, 0.62), suggesting a significant increase in mean physical activity in the intervention group compared with the control (Figure 5). The I^2 value of heterogeneity was 0%, indicating that there is no heterogeneity between studies.

3.4.3 | Eating behavior

The overall pooled standardized mean difference in eating behavior between the intervention and comparator groups was −181.71 (95% CI −304.72, −58.70), suggesting a significant decrease in mean energy intake in the intervention group compared with the control

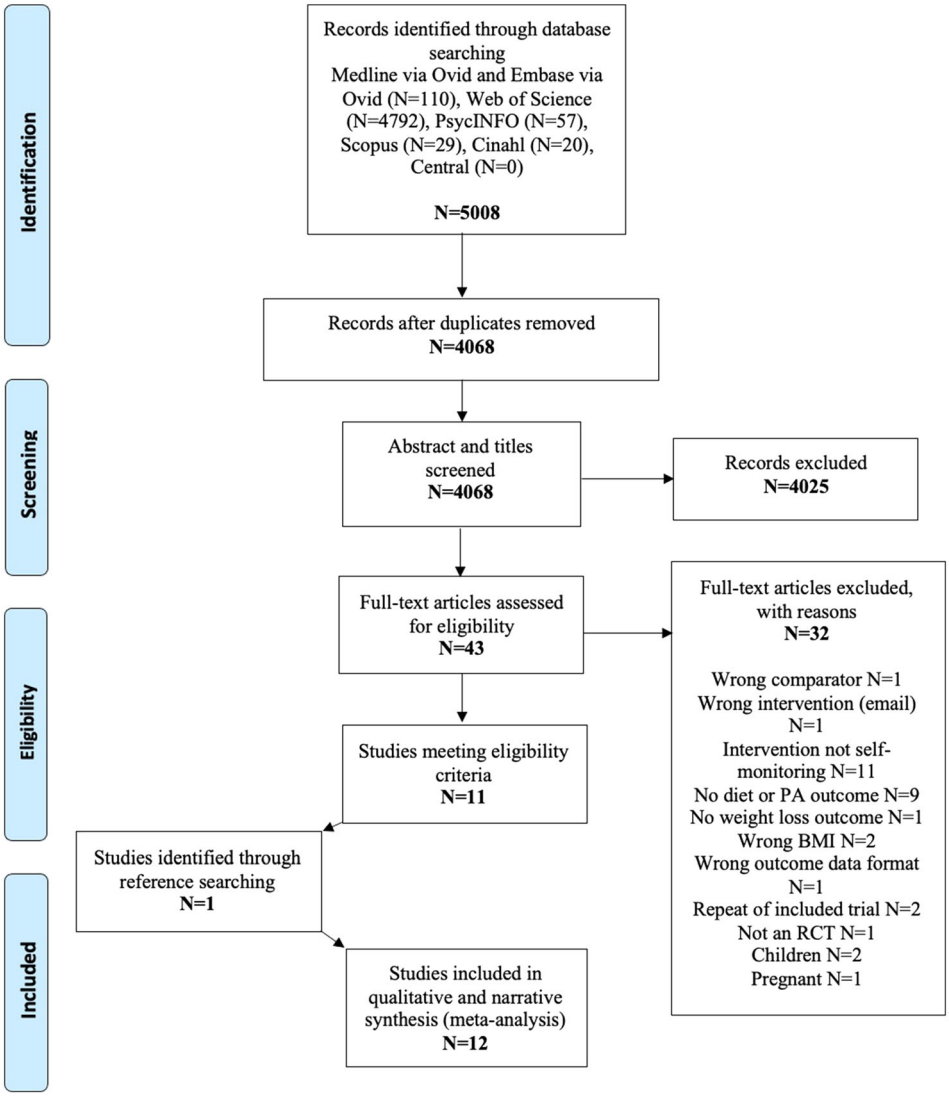

FIGURE 2 PRISMA diagram

(Figure 6). The I^2 value of heterogeneity was 0%, indicating that there is no heterogeneity between studies.

3.5 | Publication bias

Funnel plots for each of the outcomes are presented in Figures S1–S3. Overall, the funnel plots showed an unlikely possibility of publication bias.

3.6 | Subgroup analyses

The most commonly described BCT was social support (unspecified) goal setting (behavior), feedback on behavior and self-monitoring of outcome of behavior, each coded in eight studies; action planning and discrepancy between current behavior and goal, each coded in four studies; and goal setting (outcome) coded in three studies. Four studies provided tailored advice to the individual. Five studies included additional advice by a health care provider, following the digital self-monitoring intervention. The BCTs included in the intervention and comparator groups are presented in Table S4.

Subgroup analysis proved that tailored interventions were significantly more effective than nontailored interventions (tailored MD = -4.49 [95% CI −5.36, −3.62], $I^2 = 0\%$ vs. nontailored MD = −2.10 [95% CI −3.07, −1.13], $I^2 = 59\%$; $x^2 = 12.92$, $P < 0.001$), suggesting that tailored advice is significantly associated with a greater effect of digital behavioral self-monitoring on weight loss when compared with nontailored advice. A sufficient number of trials and participants were included in each subgroup, so the covariate distribution is not concerning for this subgroup analysis.[38] There was no heterogeneity for the tailored behavioral intervention subgroup ($I^2 = 0\%$, $P = 0.51$) suggesting that the estimate of the effect ($z = 10.12$) applies across the set of studies, whereas the substantial unexplained heterogeneity for the nontailored subgroup ($I^2 = 59\%$, $P = 0.02$) suggests that the effect of nontailored digital self-monitoring ($z = 4.23$) is uncertain.

There were no differences at subsets exploring the effect of other techniques on intervention effectiveness. No differences were

TABLE 1 Results of eligible studies included in the meta-analyses

Study	Outcome	Measurement units	Intervention mean	Intervention SD	Intervention *N*	Comparator mean	Comparator SD	Comparator *N*	MD or SMD and 95% CI
Allen et al[27]	Weight	kg	−5.4	4	17	−2.5	4.1	18	−2.90 (−5.58, −0.22)
	Energy intake	kcal/day	1398.1	460.4	17	1,654	463.2	18	−256 (−561.88, 49.88)
Cadmus-Bertram et al[28]	Weight	kg	−3.9	3.8	71	0.3	2.6	34	−4.20 (−5.44, −2.96)
	Physical activity	LMVPA min/day	321	124	71	267	96	34	0.46 (0.05, 0.88)
Collins et al[29]	Weight	kg	−2.98	4.05	106	0.36	2.33	104	−3.34 (−4.23, −2.45)
	Physical activity	Steps/day	9547	3752	106	7910	3511	104	0.45 (0.17, 0.72)
	Energy intake	kcal/day	2100	778	106	2289	772	104	−189 (−398.64, 20.64)
Fukuoka et al[30]	Weight	kg	−5.2	4.4	30	0.4	1.8	31	−5.60 (−7.30, −3.90)
	Physical activity	Steps/hour	640	275	30	464	320	31	0.58 (0.07, 1.09)
Glasgow et al[31]	Weight	BMI	−0.08	6.28	169	0.06	6.55	132	−0.14 (−1.60, 1.32)
Hartman et al[32]	Weight	kg	−4.4	4.3	33	−0.5	3.8	17	−3.90 (−6.23, −1.57)
	Physical activity	MVPA min/day	32	25.7	33	22	18.9	17	0.42 (−0.18, 1.01)
Hutchesson et al[33]	Weight	kg	−2.04	5.5	29	0.55	4.9	28	−2.59 (−5.29, 0.11)
	Energy intake	kcal/day	1959	832	29	1848	915	28	111 (−343.49, 565.49)
Mehring et al[26]	Weight	kg	−4.2	4.3	76	−1.7	4.1	72	−2.50 (−3.85, −1.15)
Pellegrini et al[34]	Weight	kg	−2.1	4.5	17	−1.4	3.6	17	− 0.70 (−3.44, 2.04)
	Energy intake	kcal/day	1426.7	487.8	17	1906	880.1	17	−480 (−958.10, −1.90)
Stephens et al[35]	Weight	kg	−2.4	5.2	29	1.5	5.3	30	−3.90 (−6.55, −1.25)
Watson et al[36]	Weight	kg	−3.41	3.6	32	−0.52	3.04	33	−2.89 (−4.51, −1.27)
	Energy intake	kcal/day	1462	545.1	32	1652.2	477.2	33	−190 (−439.28, 59.28)
Morgan et al[37]	Weight	kg	−5.2	5.3	34	−4.4	5.3	31	−0.80 (−3.38, 1.78)
	Physical activity	Steps/day	9807	2573	34	9134	2615	31	0.26 (−0.23, 0.75)
	Energy intake	kcal/day	1945	812	34	1993	706	31	−48 (−417.13, 321.13)

Note: Results are reported in mean, standard deviation (SD), number of participants (*N*), and 95% confidence intervals (CI). Effect estimates are reported in mean differences (MD) for weight and energy intake, and standardized mean difference (SMD) for physical activity. Data for weight loss are adjusted for baseline values.

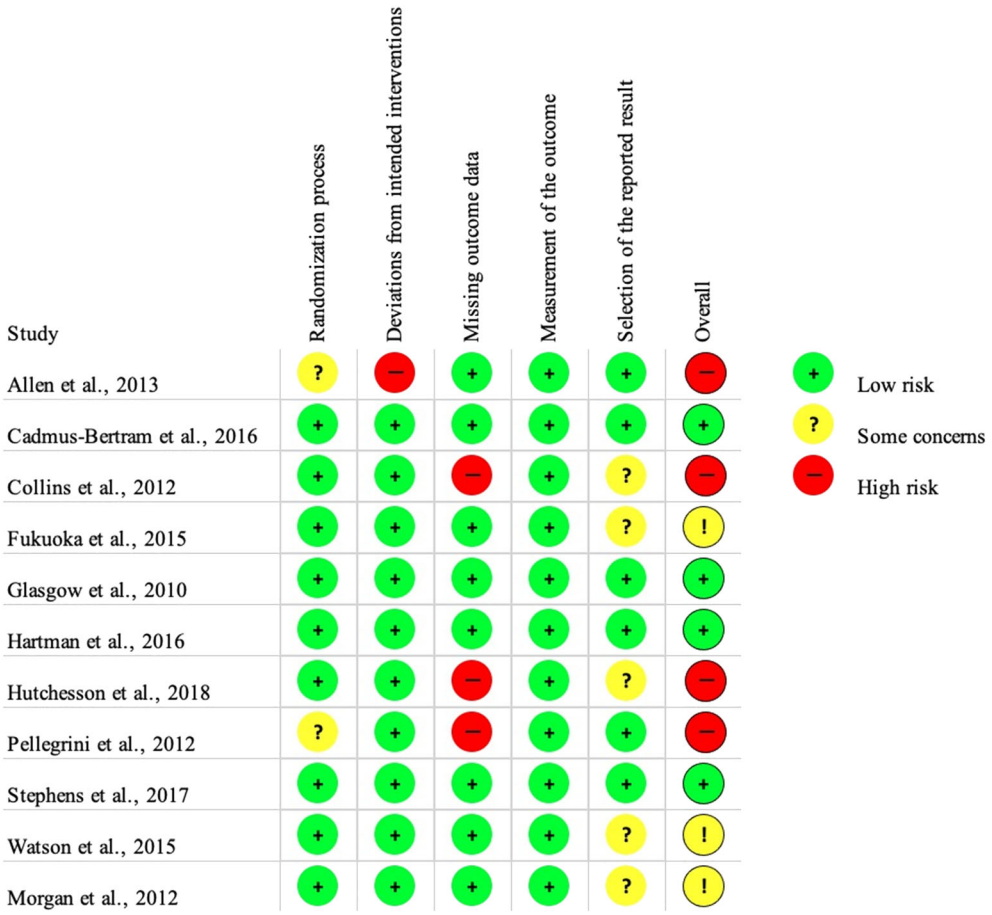

FIGURE 3 Risk of bias assessment

observed on whether self-monitoring was followed up briefly by a health care provider advice or not (MD = −2.68 [95% CI −4.03, −1.33], $n = 5$ vs. MD = −3.02 [−4.36, −1.68], $n = 7$; $x^2 = 0.12$, $P > 0.05$), suggesting that additional advice by a health care provider might not significantly account for the effectiveness of the primarily digitally delivered behavioral intervention.

4 | DISCUSSION

4.1 | Main findings

The results from the meta-analyses suggest that digital self-monitoring behavioral interventions of physical activity and diet are effective at supporting weight loss, improving moderate physical activity and reducing calorie intake, compared with interventions that do not enable digital self-monitoring of both of these behaviors. The observed positive effects recommend that digital self-monitoring of eating behavior and physical activity is a promising way to support adults with overweight or obesity lose weight, at least in the short term. Tailored behavioral interventions were significantly more effective than nontailored interventions, suggesting that tailored behavioral advice can significantly enhance the effect of digital self-monitoring on weight loss.

4.2 | Strengths of studies

A strength of included studies was the RCT study design that minimizes possible selection biases and confounding that are common in observational studies.[39] The RCT design accounts for both known and unknown confounders through randomization, therefore, the effect size is largely unbiased. Another benefit of these studies was that they included a defined population of people who could directly benefit from these interventions. Weight loss and physical activity outcomes were also measured objectively by studies which also minimizes potential bias in their measurement.

4.3 | Limitations of studies

The quality of the evidence provided by the included studies in this review was variable. Five out of the 12 studies were assessed to be at high risk of bias, and three had some concerns of bias with only four studies deemed to be at low risk of bias. Major limitations of the included studies were missing outcome data and deviation from the intended intervention, and some concerns were for bias arising from the randomization process and selection of reported results.

The nature of digital interventions means that they are constantly evolving and updating. Technological updates are therefore not

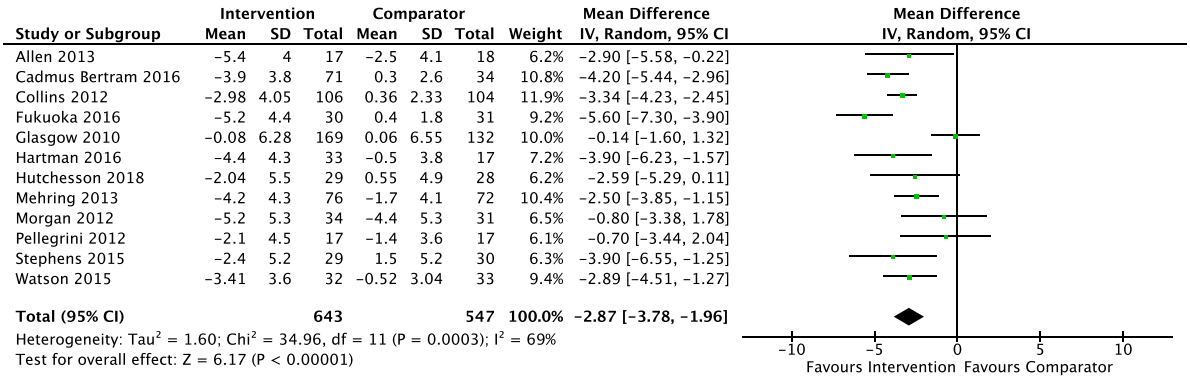

FIGURE 4 Meta-analysis results for weight loss

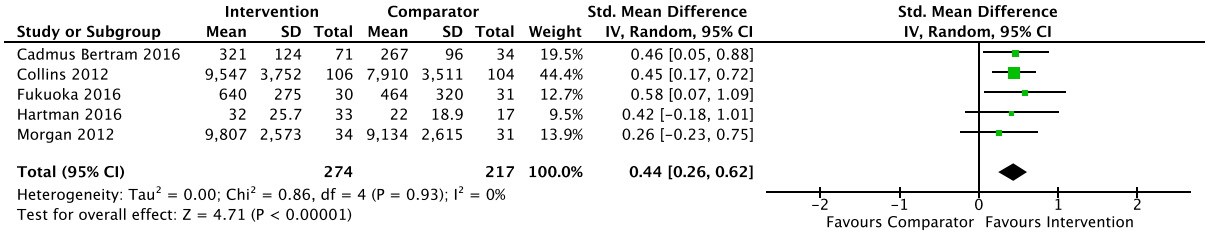

FIGURE 5 Meta-analysis results for physical activity

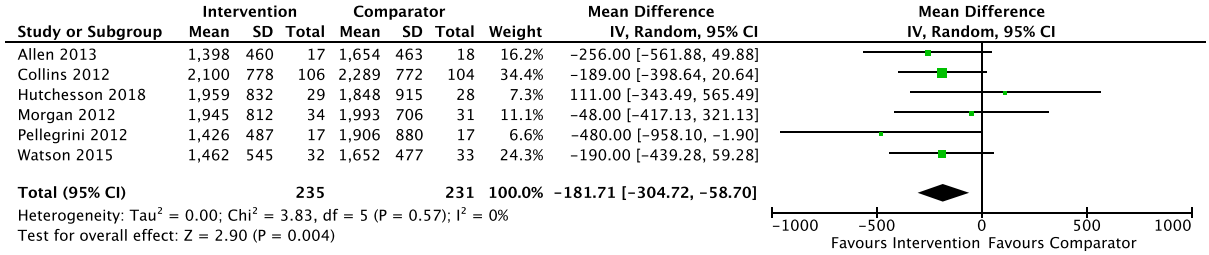

FIGURE 6 Meta-analysis results for energy intake

unexpected and occurred for example in Hartman et al.[32] In this particular study, the update to the application's sensing technology did not result in deviations from the intended intervention content and did not influence the outcome or the risk of bias assessment. However, technological updates could potentially result in deviations to the intervention that could bias the outcome.[20] It would have been useful if studies had provided a detailed description of the intervention and described potential deviations during implementation, to enable a more accurate assessment of the potential risk of bias.

In addition, in all studies participants were unblinded to the intervention. Although this did not influence the results of the risk of bias assessment, knowledge of group assignment may influence the behavior of participants in the trial and their responses to subjective outcome measurement. For example, knowledge of the intervention received may have resulted in participants providing biased results for the self-reported measured outcomes,[40] such as energy intake. Therefore, the results of the energy intake meta-analyses should be interpreted with caution.

4.4 | Strengths of review

A strength of this review was the systematic search of the literature that was carried out using a pre-specified search strategy that encompassed search terms previously used by other similar reviews. As a result, a sufficient number of studies were retrieved, and the references of these studies were also searched to identify additional studies. The screening process was completed independently by the two reviewers and all data were double coded and checked by a third reviewer, which improved the reliability of the review process. Overall, twelve studies were identified which provided adequate data for the meta-analyses and subgroup analysis to address the primary and secondary questions of this review.

4.5 | Limitations of review

One of the major limitations of this review was the absence of a risk of bias assessment for the secondary outcomes, particularly for energy intake that were measured subjectively. If this assessment had been performed, it is likely that the risk of bias results for outcome assessment would have been different from those of the primary outcome.

Another limitation was that no grey literature was included, and more databases could have been searched. However, the inspection of the funnel plot and the fail-safe *N* suggested that the result of this review is unlikely to have been influenced by publication bias.

4.6 | Public health implications

The ramifications and costs of a largely overweight population are both economic and health-related. The estimated annual cost of obesity to the US health care system is $149.4 billion,[41] and the annual productivity cost of obesity-related absenteeism ranges between $3.38 and $6.38 billion.[42] Hypertension, heart disease, diabetes, stroke, and cancer are just some of the life-threatening health conditions associated with obesity.[42] Digital health interventions provide a novel public health opportunity to change health behaviors in a way that is affordable, wide-reaching, and impactful to tackle obesity and overweight.

Weight loss of at least 0.5 kg has been associated with 54% lower risk of overall mortality.[43] The findings from our meta-analysis revealed a mean weight loss of 2.87 kg, suggesting meaningful and clinically significant effect of behavioral self-monitoring on reducing obesity-related morbidity and mortality.[44]

4.7 | Future research and implications for theory and practice

The findings of this review suggest that digital self-monitoring behavioral interventions is an effective and potentially a cost-effective method to promote weight loss. Weight loss has been directly linked with important health indicators, and these positive findings suggest a promising outlook for implementing these kinds of digital interventions in health care practice. Targeting both eating and physical activity behaviors in a single intervention to promote weight loss may alleviate pressure on health care and public health resources that tackle these behaviors individually to improve weight loss and quality of care. However, before implementing these interventions in practice, we need to understand what can be done to improve their sustained effectiveness to achieve clinically meaningful results. This involves identifying priority areas for their implementation in current practice to inform service provision.

One area that warrants further research is the frequency, duration, and level of adherence to behavioral self-monitoring that is necessary to achieve significant and sustained effects on weight loss, and improved physical activity and eating behaviors. Moreover, currently remains much work to understand how to improve users engagement with digital behavior change interventions.[45] Turner-McGrievy et al explored adherence with dietary mobile self-monitoring and found that even with the use of mobile methods, adherence rates drop over time.[46] We must therefore find ways to make self-monitoring more engaging at points where adherence begins to decline. However, a recent review by Patel et al on digital self-monitoring suggested that adherence to digital self-monitoring is feasible.[17]

This review found interventions that conveyed tailored behaviour change techniques and strategies to the participants more effective at supporting weight loss than those that did not. For example, Allen et al provided preset behavioral goals for all participants, whereas Fukuoka et al provided personalized behavioral goals and had higher effect at improving weight loss. This finding suggests that differences between tailored or nontailored advice and support could explain the differences in intervention effect.

Public health recommendations highlight the need for more research to develop and evaluate effective digital lifestyle interventions for people with obesity or overweight.[47] This review demonstrated that digital self-monitoring interventions could be a way forward to achieve effective weight loss in this population. However, current trials are of short duration, with small samples and lack of rigorous outcome measurements.[48] Longer trials beyond 6 months are needed to determine whether the effective components found in this review could support sustained weight loss and thus promote clinically meaningful effects.[47] Of the two studies in this review that exceeded 6 months in length, the outcomes for weight loss, physical activity, and energy intake did not appear to differ compared to those less than 6 months. Our findings therefore suggest that tailored digital self-monitoring might be effective regardless of whether individuals are in an active weight loss phase or weight loss maintenance phase.

Other implications for practice involve establishing which type of digital delivery mode is most acceptable to those with obesity or overweight and most efficient at facilitating complex behavior change interventions. Few studies in the literature have compared digital delivery modes; therefore, it is currently unknown whether and which digital delivery mode might be most efficient to support patients' self-regulatory processes.[48] A benefit of this current research is that a range of digital delivery modes have been trialed and deemed acceptable.

Future research could usefully explore the acceptability of the digital self-monitoring in adjunct to current weight management services. The combination with the nondigital elements should also be explored to understand whether it is feasible for digital self-monitoring behavioral interventions to effectivelly complement current weight management practices.

5 | CONCLUSION

The results of the meta-analysis suggest that digital-self monitoring of eating behavior and physical activity is significantly effective at improving weight loss, increasing moderate physical activity and

reducing calorie intake in adults with obesity or overweight. Subgroup analysis found that tailored advice significantly modified the intervention effect of digital self-monitoring on weight loss. These findings support the digital self-monitoring of behaviors as an effective and low cost solution to tackle obesity and overweight. Robust evidence is required to evaluate their effectiveness and cost-effectiveness as an adjunct to weight management services.

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CONFLICT OF INTEREST

The authors declared no conflicts of interest.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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